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ARB's Study of Emissions from "Late-model" Diesel and CNG Heavy-duty Transit Buses: *Preliminary Nanoparticle Measurement Results*

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SUMMARY

This paper provides an overview of recent activities led by the Air Resources Board (ARB) to characterize emissions from late-model heavy-duty diesel and compressed natural gas (CNG) transit buses. The project was intended to obtain a "snap shot" of the emissions profile from late-model in-use public transit buses in operation in Los Angeles, California, rather than a fleet average. Here, we report preliminary ultrafine (<100nm) particle measurements obtained over the Central Business District (CBD) cycle and a steady-state (SS) 55 mph "loaded" cruise condition. For the SS runs, the chassis dynamometer applied both road load and an additional experimentally-determined vehicle-specific load corresponding to approximately 60% of the available engine power. Emission testing was conducted at ARB's Heavy-duty Vehicle Emissions Laboratory (HDVEL) located in downtown Los Angeles, California. Three vehicle configurations were investigated: *i*) a CNG 40-passenger New Flyer bus equipped with a DDC Series 50G engine, *ii*) a "baseline" diesel 40-passenger New Flyer bus equipped with a DDC Series 50 engine and a catalyzed muffler, and iii) the same diesel vehicle retrofitted with a Johnson Matthey Continuously Regenerating Technology (CRT™) diesel particulate filter (DPF) in place of the muffler. The CNG bus was not equipped with any aftertreatment. The diesel vehicle was fueled by ARCO ECD-1 (sulfur ≤ 15ppm). Other duty cycles of interest in this study were idle operation, the Urban Dynamometer Driving Schedule (UDDS), and the New York City Bus Cycle (NYBC). Collection of particulate matter (PM) samples over multiple cycles was performed for subsequent chemical and mutagenic analyses. A Micro-orifice Uniform Deposit Impactor (MOUDI) and an Electrical Low Pressure Impactor (ELPI) were used for size-selective measurements. Two Scanning Mobility Particle Sizers (SMPS) were used to characterize ultrafine emissions at two sampling locations. One SMPS station was equipped with a partial-flow ejector-type mini-diluter for sampling raw vehicle exhaust. Measurements were conducted for two dilution ratios, 65 and 18. The second SMPS sampled a portion of the diluted exhaust directly from the full-exhaust Constant Volume Sampling (CVS) dilution tunnel. This sampling point corresponded to the location where conventional total PM and gaseous samples were collected.

BACKGROUND

The California Clean Air Act (CCAA) mandates the ARB to achieve the maximum degree of emission reductions from all on- and off-road mobile sources in order to attain the state ambient air quality standards. The identification of diesel PM as a Toxic Air Contaminant (TAC) in California prompted the development of ARB's Diesel Risk Reduction Plan.[1] Accordingly, the ARB is currently involved in a number of regulatory strategies focused on emissions reductions from on-road and off-road engines. A number of control measures for new and existing engines have been identified. One recommendation to reduce diesel PM emissions promotes the use of DPF's and alternative fuels.[2] In addition, ARB and the South Coast Air Quality Management District (SCAQMD) adopted new rules that promote the use of CNG technology for urban transit buses. The study described here expands the current research database on "clean" diesel and CNG transit bus emissions and offers relevant information for future rule-making.

Internal combustion engines have been identified as significant sources of submicron particulate matter. Primary diesel exhaust particles of 20-50 nm diameter have been measured, but there is no widely accepted test protocol for accurately measuring these nanoparticles (<50nm) under laboratory conditions that represent "real-wold" dilution conditions.[3] Many factors highlight recent interest in ultrafine emissions: 1) the Health Effects Institute recently released the first report that indicates an association between ultrafine and fine particles and human mortality;[4] 2) the number of diesel on-road vehicles and their average annual vehicle miles traveled are steadily increasing;[5] 3) fuel composition is changing; 4) changes in diesel engine designs to meet stringent mass emission regulations are believed to increase nanoparticle number concentrations.[6]

This work was designed to characterize the ultrafine particles emitted by diesel and natural gas vehicles by both physical and chemical techniques.

ULTRAFINE PARTICLE MEASUREMENTS

Particle sizing was conducted simultaneously (1) with the use of a mini-dilution system for diluting raw vehicle exhaust and (2) directly on samples drawn from the CVS tunnel. Exhaust was directed to the CVS through a 6 in stainless steel corrugated pipe. A ¼ in stainless steel heated line directed raw exhaust at approximately 0.5 Lpm into a single-stage, ejector-type Dekati Ltd mini-diluter. Dilution air was provided by an oil-free compressor and fed through a HEPA/carbon/dessicant capsule into the mini-diluter at a nominal rate of 35 Lpm. Ultrafine measurements for the diesel vehicle were conducted at a dilution ratio of 65. The CNG vehicle was tested at two dilution ratios, 65 and 18. These were chosen to bracket the conditions used in other particle sizing studies of natural gas vehicles.[7] From the mini-diluter, the aerosol was directed through an insulated 1 in diameter 6 ft long stainless steel residence chamber. The residence time in the chamber was approximately 1-1.5 sec. From this chamber, a "Y" connection directed the sample to both the SMPS and the ELPI. Conductive silicon tubing was used between the chamber and the instruments. The temperatures of the raw exhaust, the diluted sample and the residence chamber wall were monitored continuously. Humidity was monitored only for ambient air. A constant volume displacement pump drew 30 Lpm for the ELPI. The SMPS's were operated at 1.5 Lpm – using TSI's Aerosol Instrument Manager, version 4 software. The SMPS included a model 3080 electrostatic classifier with a model 3081 long differential mobility analyzer and a 3025A ultrafine condensation particle counter. A quality assurance protocol for consistent use of the SMPS's was implemented. This included daily checks and routine verification using NaCl and polystyrene latex spheres and a TSI electrospray.

The SMPS's were used to measure particles under both steady state and transient conditions. During steady state, idle, and for tunnel blanks, the SMPS's were operated on "size-scan" mode. Two minute full scans were collected for measuring particles in the size range 6 nm to 237 nm. During the transient cycles, the SMPS's were operated on "size-filtered" mode by collecting 300 sec particle concentrations in real time at one mobility diameter. Multiple runs were conducted and typically 8, 20, 80, and 140 nm particles were measured.

GENERAL REMARKS

In this presentation, preliminary results for the CBD and SS tests are discussed. This partial data set indicates that a CRT-equipped vehicle fueled by low-sulfur diesel efficiently reduces not only total PM emissions, but also the ultrafine number concentrations in the particle size range from 6 to 237 nm. In contrast, while the total ultrafine particle counts in CNG exhaust were comparable to the total particle counts in the CRT-equipped diesel exhaust over SS operation, the particles in CNG exhaust were significantly smaller. Over the CBD, CNG nanoparticles were also smaller and more numerous than those measured for both the baseline and CRT diesels. Two sampling/dilution setups were used for particle sizing. Although there were clear differences in number concentrations due to distinct dilution conditions between the CVS and mini-diluter, the relative shapes of the size distributions were surprisingly well correlated between vehicles. However, vehicle/tunnel conditioning was found to play a significant role when using the CVS to determine total particle numbers. Precise testing protocols are needed to alleviate the uncertainty in background measurements.

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